Power Systems Control
from Circuits to Economics

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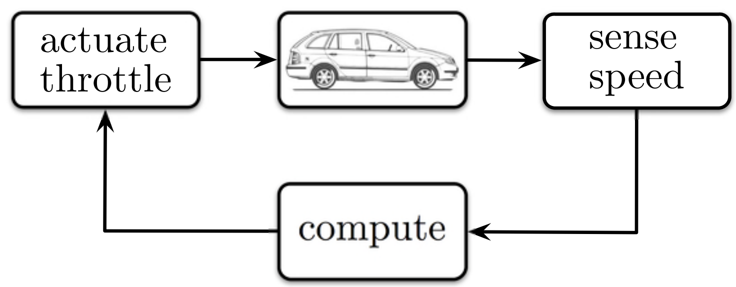
Who are we?

Florian

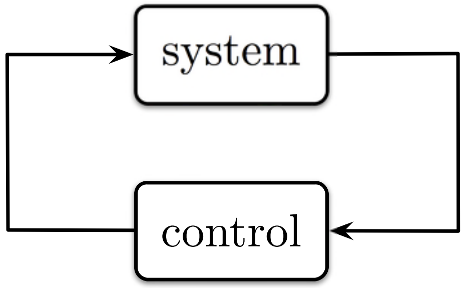
Andrej

why should control engineers or even pure control theorists care about power systems ?

The "simple" control loop



The "simple" control loop

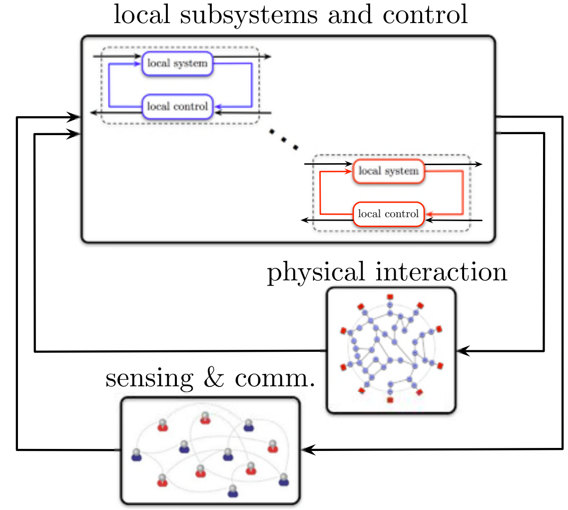


"Simple" control systems are well understood.

"Complexity" can enter this control loop in many ways:

models, disturbances, constraints, uncertainty, optimality,
. . . all of which are embodied in power systems.

More recent focus: "complex" distributed decision making

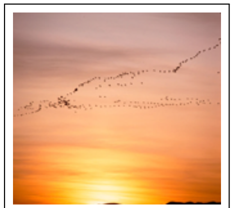


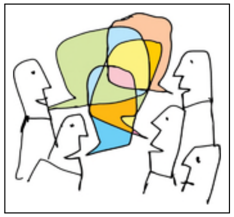
Such distributed systems include **large-scale** physical systems, engineered **multi-agent** systems, & their interconnection in **cyber-physical** systems.

Timely applications of distributed systems control

often the centralized perspective is simply not appropriate


robotic networks


decision making


social networks


sensor networks


self-organization


pervasive computing


tra c networks


smart power grids

what makes power systems (IMHO) so interesting?

My main application of interest – the power grid

NASA Goddard Space Flight Center

- **Electric energy** is critical for our technological civilization
- Energy supply via **power grid**
- **Complexities**: nonlinear, multi-scale, & non-local

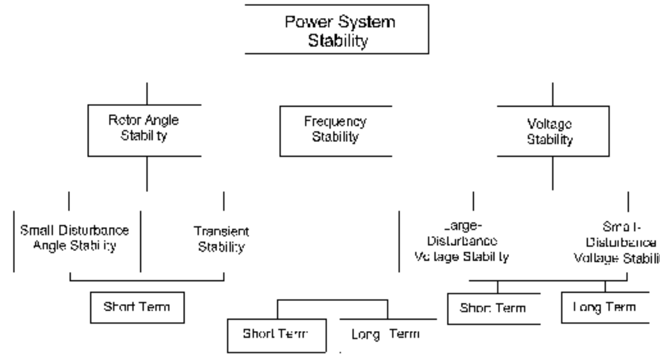
One system with many dynamics & control problems

IEEE TRANSACTIONS ON POWER SYSTEMS, VOL. 19, NO. 2, MAY 2004 1387

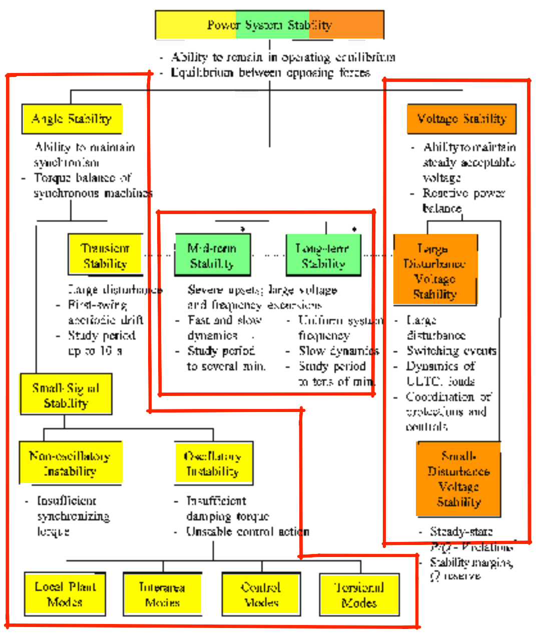
Definition and Classification of Power System Stability

IEEE/CIGRE Joint Task Force on Stability Terms and Definitions

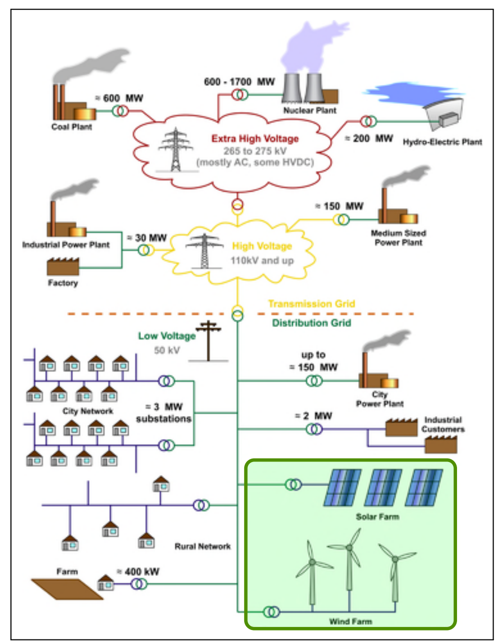
Prabha Kundur (Canada, Convener), John Paserba (USA, Secretary), Venkat Ajjarapu (USA), Göran Andersson (Switzerland), Anjan Bose (USA), Claudio Canizares (Canada), Nikos Hatziargyriou (Greece), David Hill (Australia), Alex Stankovic (USA), Carson Taylor (USA), Thierry Van Cutsem (Belgium), and Vijay Vittal (USA)



Many aspects: spatial/temporal scales, cause & effect, ...



(Conventional) operation of electric power networks



Top-to-bottom operation:

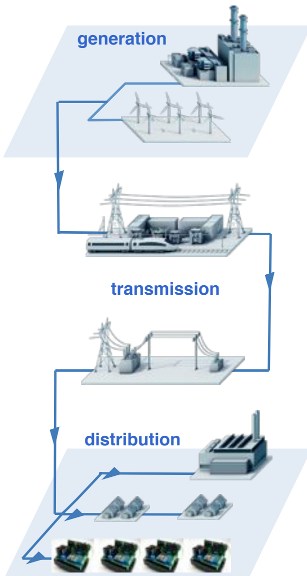
- **purpose** of electric power grid: generate/transmit/distribute
- **operation**: hierarchical & based on bulk generation
- things are changing ...

A few (of many) game changers

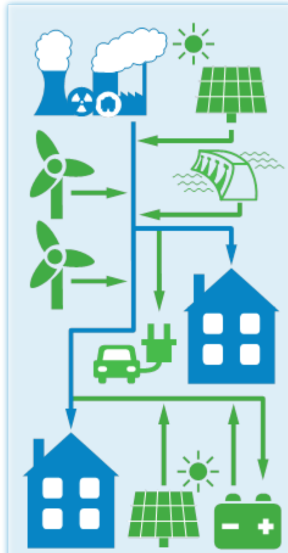
synchronous generator
⇒ power electronics

scaling

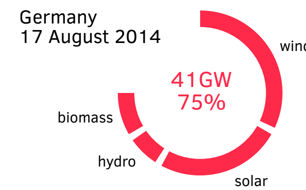
distributed generation

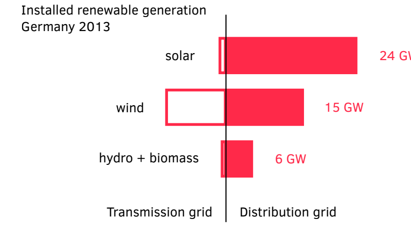


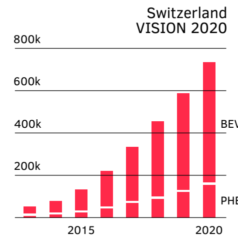
other paradigm shifts

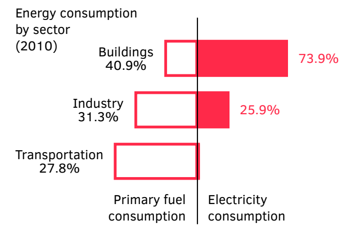


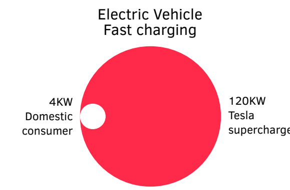
A little bit of drama: examples close to home



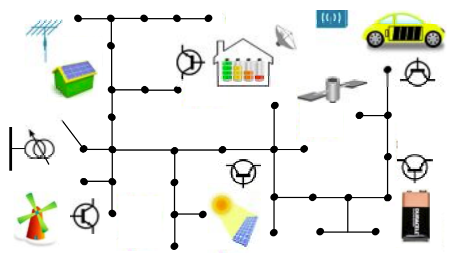








Paradigm shifts & new scenarios . . . in a nutshell



1. controllable fossil fuel sources ⇒ stochastic renewable sources
2. centralized bulk generation ⇒ distributed low-voltage generation
3. synchronous generators ⇒ low/no inertia power electronics
4. generation follows load ⇒ controllable load follows generation
5. monopolistic energy markets ⇒ deregulated energy markets
6. centralized top-to-bottom control ⇒ distributed non-hierarchical control
7. human in the loop & heuristics ⇒ \smart" real-time decision making

Challenges & opportunities in tomorrow's power grid

www.o thegridnews.com

☹perational challenges

- more uncertainty & less inertia
- more volatile & faster uctuations
- deregulation & decentralization

☺pportunities

- re-instrumentation: comm & sensors and actuators throughout grid
- elasticity in storage & demand
- advances in understanding & control of cyber-physical & complex systems

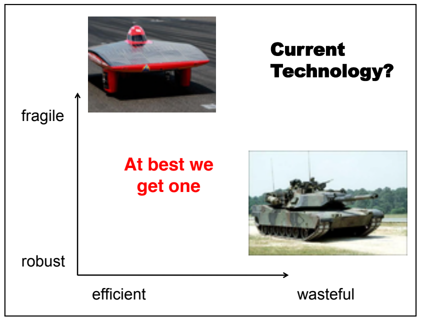
Some profound insights by the giants in the field

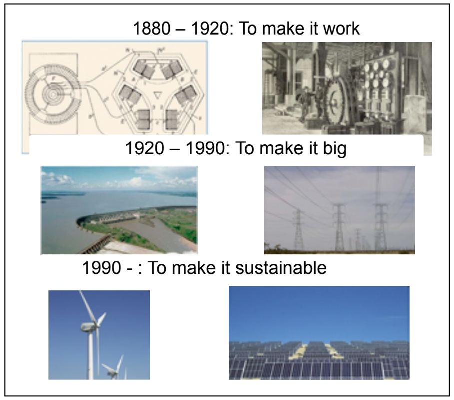
trade-o s & hard limits in control

[J. Doyle, UCSB '12]

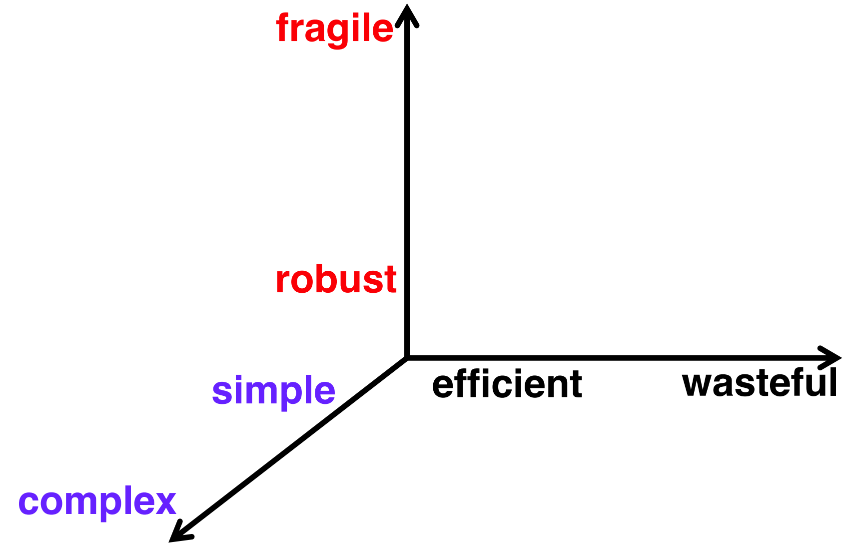
a third challenge in power systems

[G. Andersson, LANL '14]





We should keep John's and Göran's trade-offs in mind



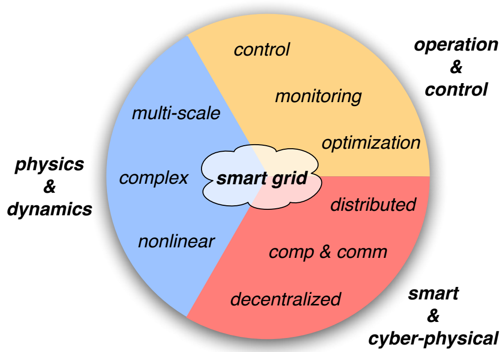
The envisioned power grid

complex, cyber-physical, & "smart"

⇒ smart grid **keywords**

⇒ **interdisciplinary**: power, control, comm, optim, econ, physics, . . . industry, & society

⇒ **research themes**: *trade-offs in robustness, complexity, & efficiency*



"[It remains] to put some serious science into the idea." | [David Hill, PESGM '12]

Power Systems Control — from Circuits to Economics

Wednesday, February 17, 2016

10.00 – 11.00	Registration	
11.00 – 11.30	Florian Dörfler	General introduction
11.30 – 12.30	Florian Dörfler	Power System Modeling
12.30 – 14.00	Lunch	
14.00 – 15.00	Florian Dörfler	Power System Stability Control I
15.00 – 15.15	Break	
15.15 – 16.00	Florian Dörfler	Power System Stability Control I
16.00 – 17.30	Exercises	

Thurday, February 18, 2016

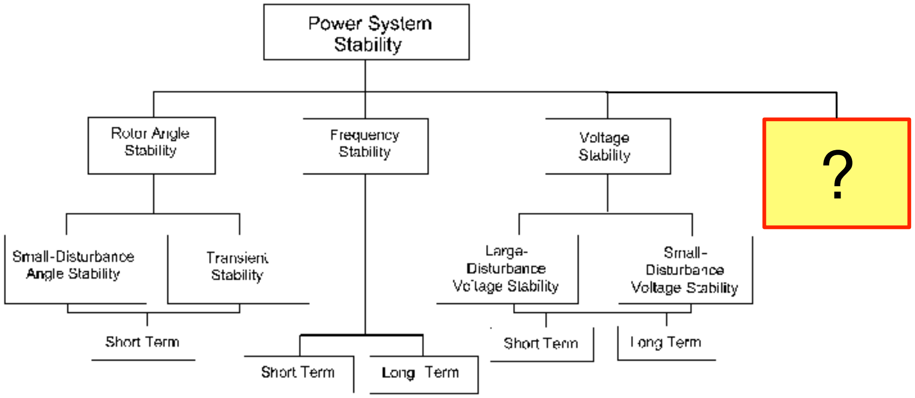
09.00 – 10.15	Florian Dörfler	Power System Stability Control II
10.15 – 10.30	Break	
10.30 – 11.30	Florian Dörfler	Power System Stability Control II
11.30 – 12.30	Exercises	
12.30 – 14.00	Lunch	
14.00 – 15.00	Andrej Jokic	Power System Economics I
15.00 – 15.15	Break	
16.00 – 17.00	Exercises	
19.00	Dinner	

Friday, February 19, 2016

09.00 – 10.15	Andrej Jokic	Power System Economics II
10.15 – 10.30	Break	
10.30 – 11.30	Andrej Jokic	Power System Economics II
11.30 – 12.30	Exercises	
12.30 – 13.30	Lunch	
13.30 – 14.30	Discussion of future research topics	
14.30	Drinks and closing	

A preview — to be resolved on the last day

The future will hold a new (and very dominant) stability issue



let's start off with a quiz:

what is your background?

why are you interested in power?

what are your expectations?